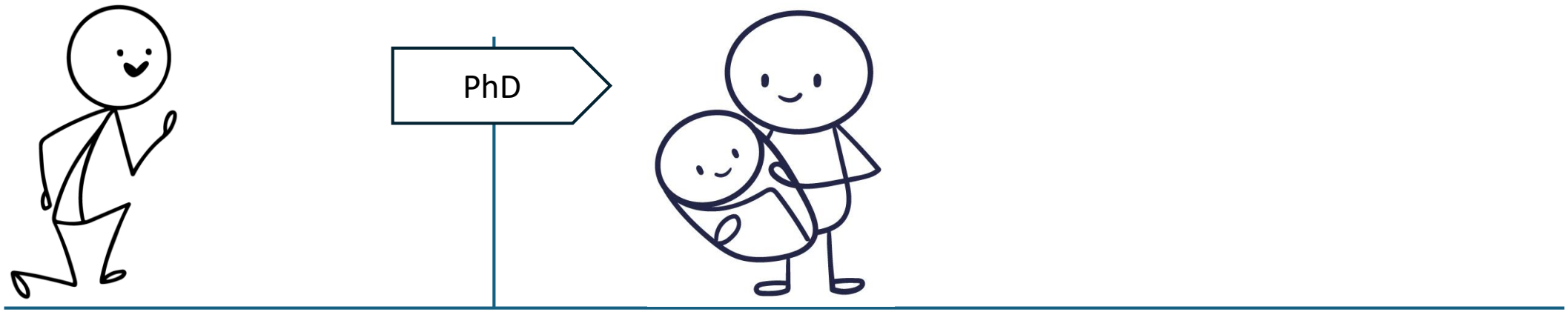
Studies of the driver and study of the plasma ramp

AWAKE Collaboration meeting – November 2024

Jan Pucek

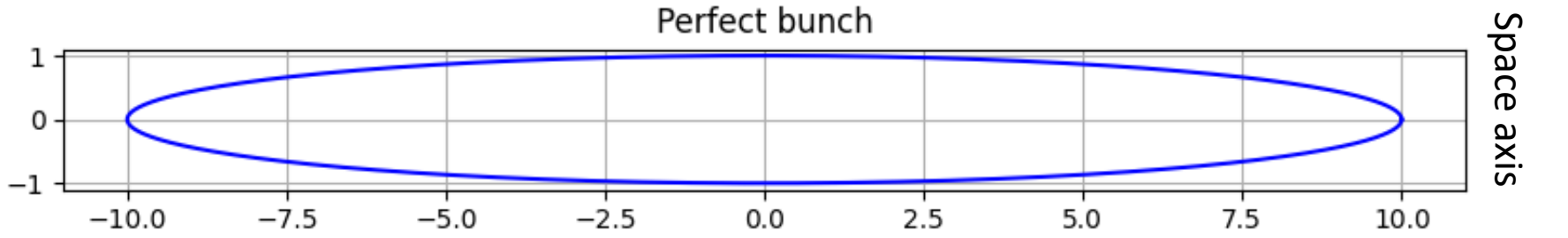


*Designed by Freepik

Presentation outline

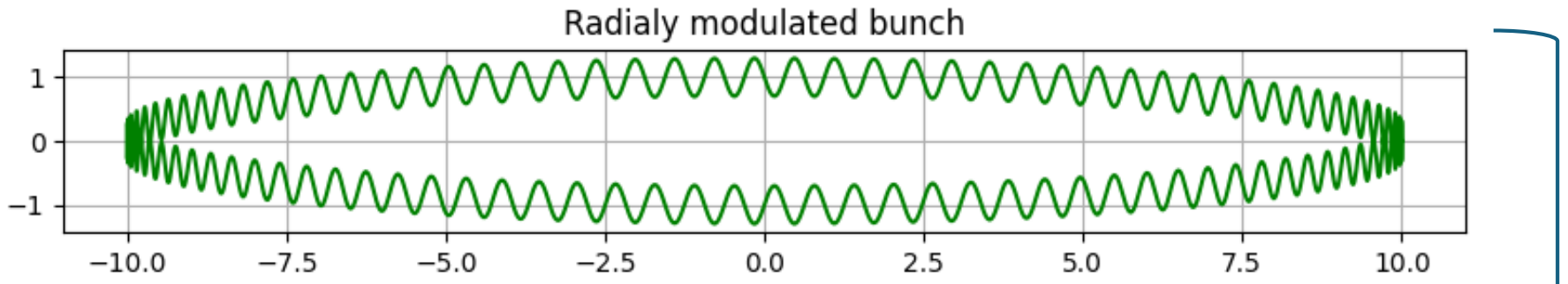
- Self modulation instability – study of the driver
  - Features within the incoming bunch
  - Transition between seeding and instability
- Study of the density ramp at the plasma entrance
  - aka ”the electron witness survivalability study”

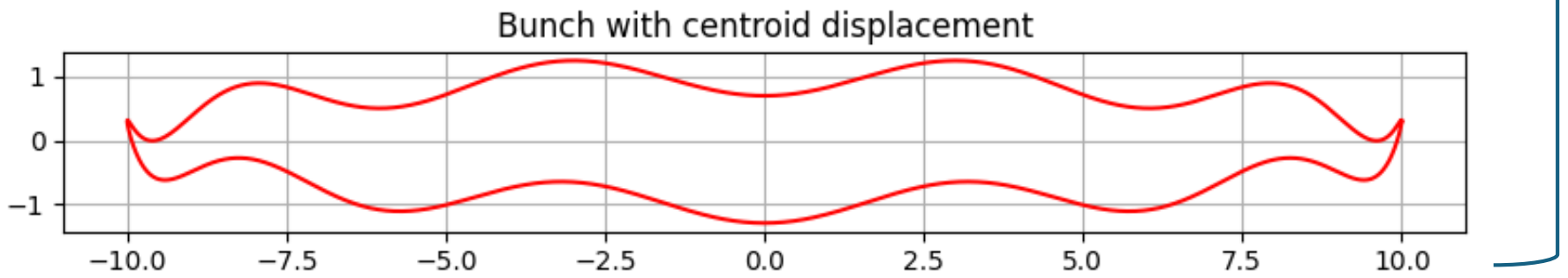
Incoming proton bunch structure



Space axis

time axis





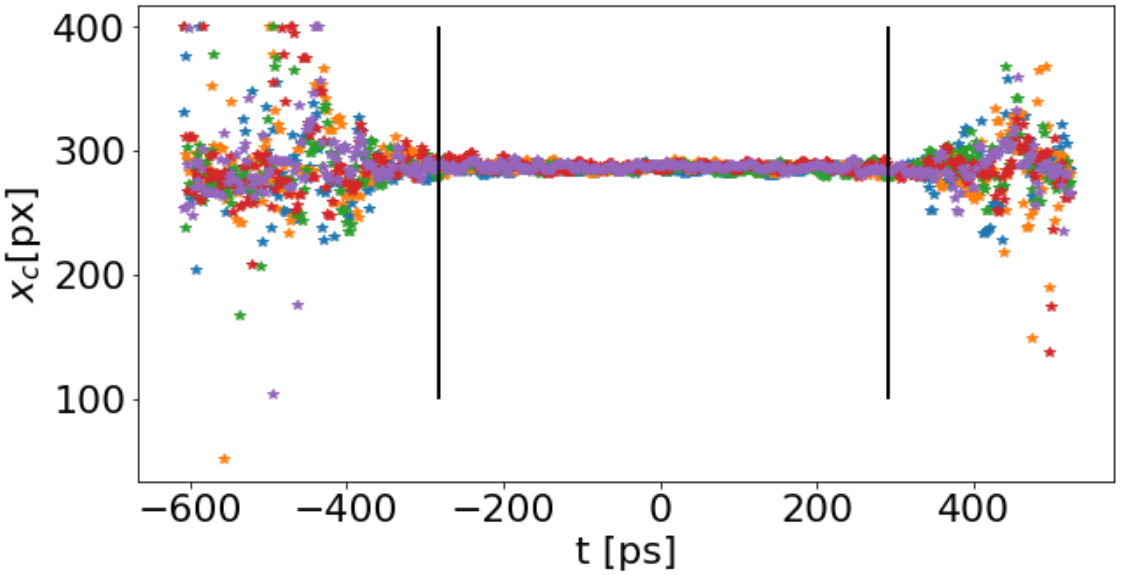
This is what we are looking for

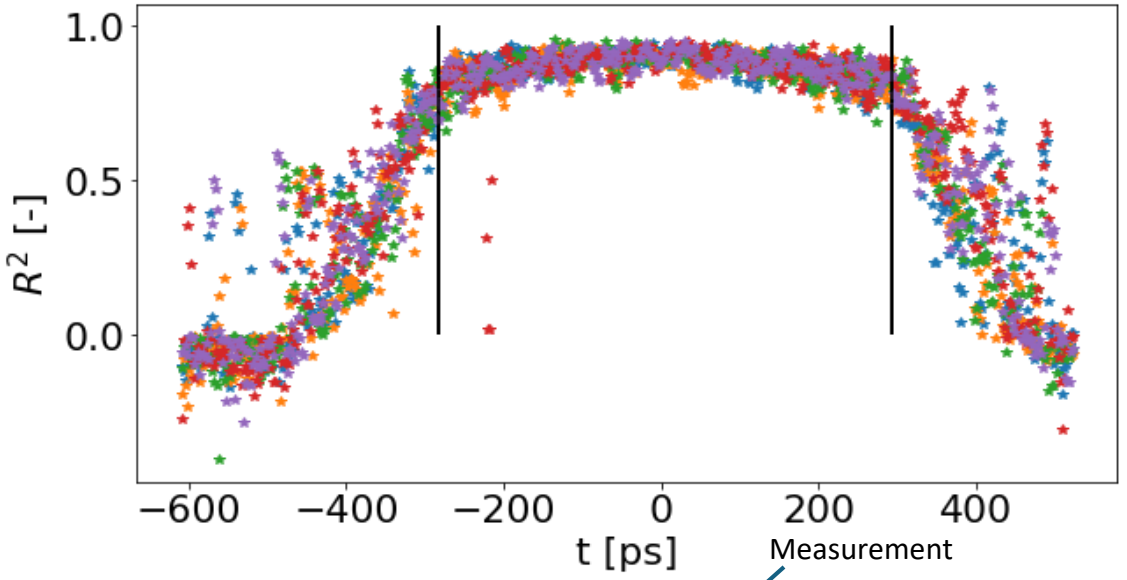
Incoming proton bunch features

- Search for a potential seed present in the incoming driver
- Streak camera images of the proton bunch propagating through vacuum (to the OTR screen)
- Centroid displacement = hosing seed
  Radial size modulation = SMI seed
- Calculate the power spectrum – reoccuring frequencies?

Measurement

- Several datasets of proton bunches measured at two timescales (1ns, 210ps)
- Identified center and radial size for each pixel row (Gaussian fit)





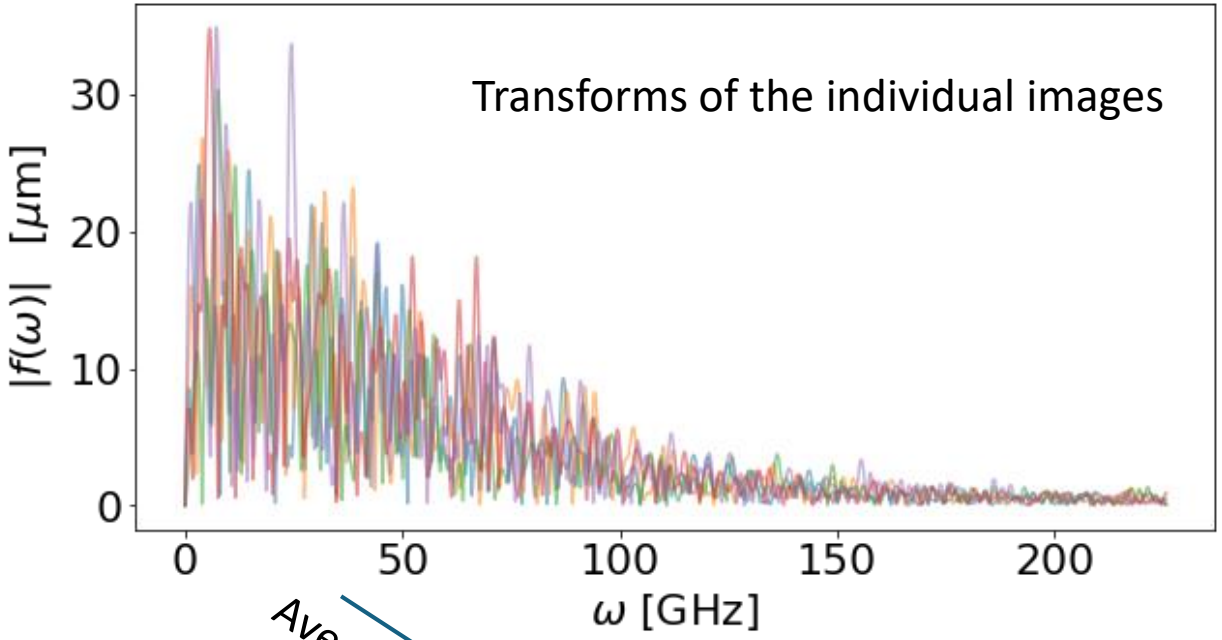
Measurement

Model

$$R^2 = 1 - \frac{\sum_i (y_i - f_i)^2}{\sum_i (y_i - \overline{y})^2}$$

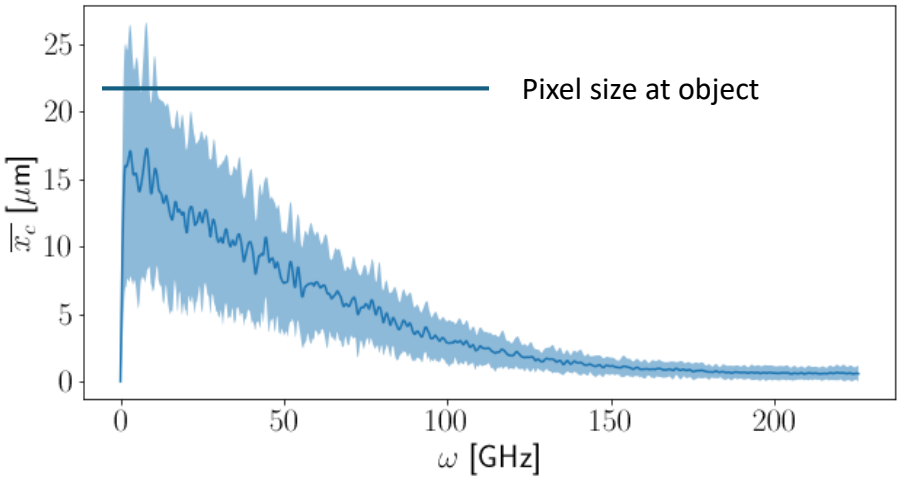
Mean

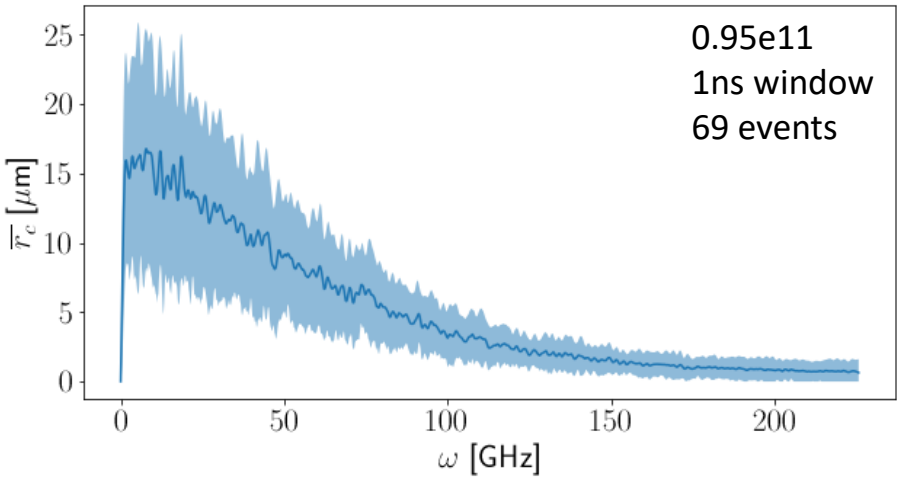
Results



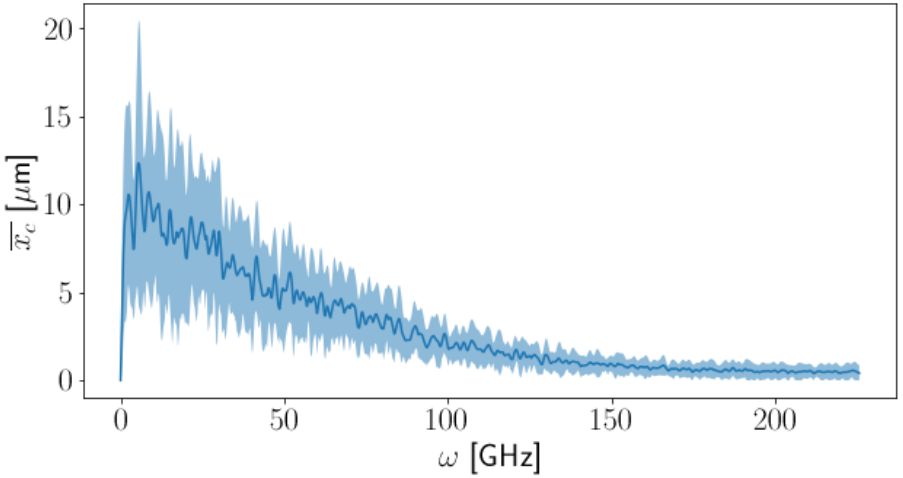
Averaged absolute value of the FT for the dataset

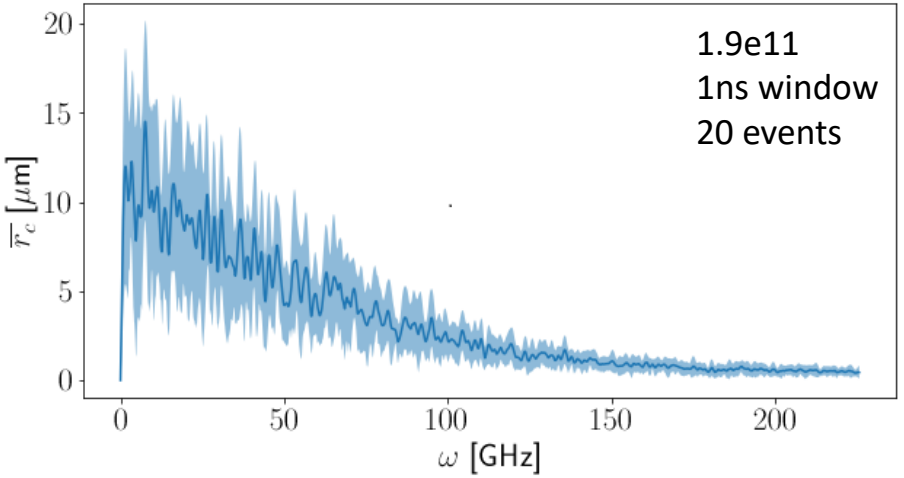
- The absolute value of the FT is averaged for each dataset
- No signs of persisting seed

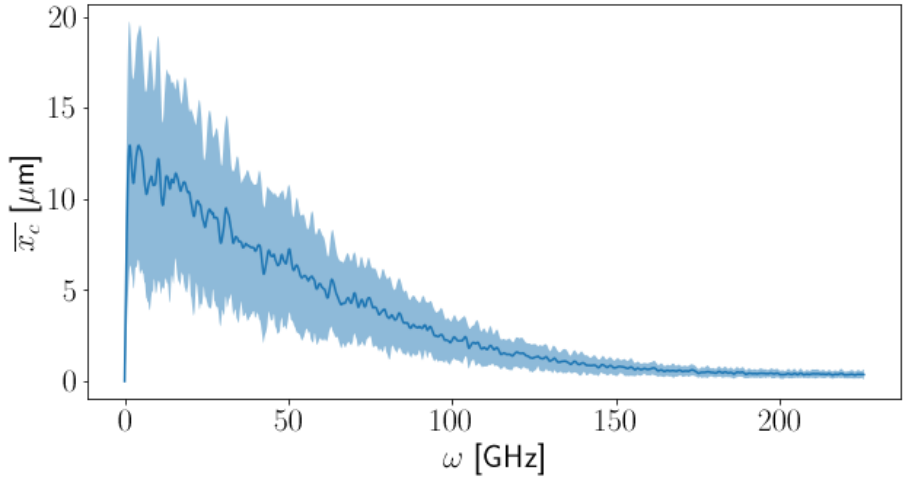


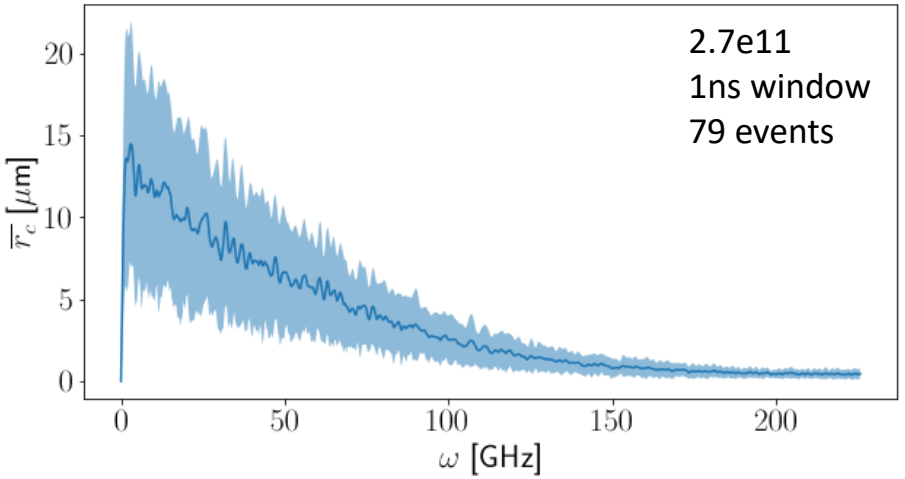


Results


20
15
10
5
0
$\overline{x_c}$ [μm]
0
50
100
150
200
ω [GHz]

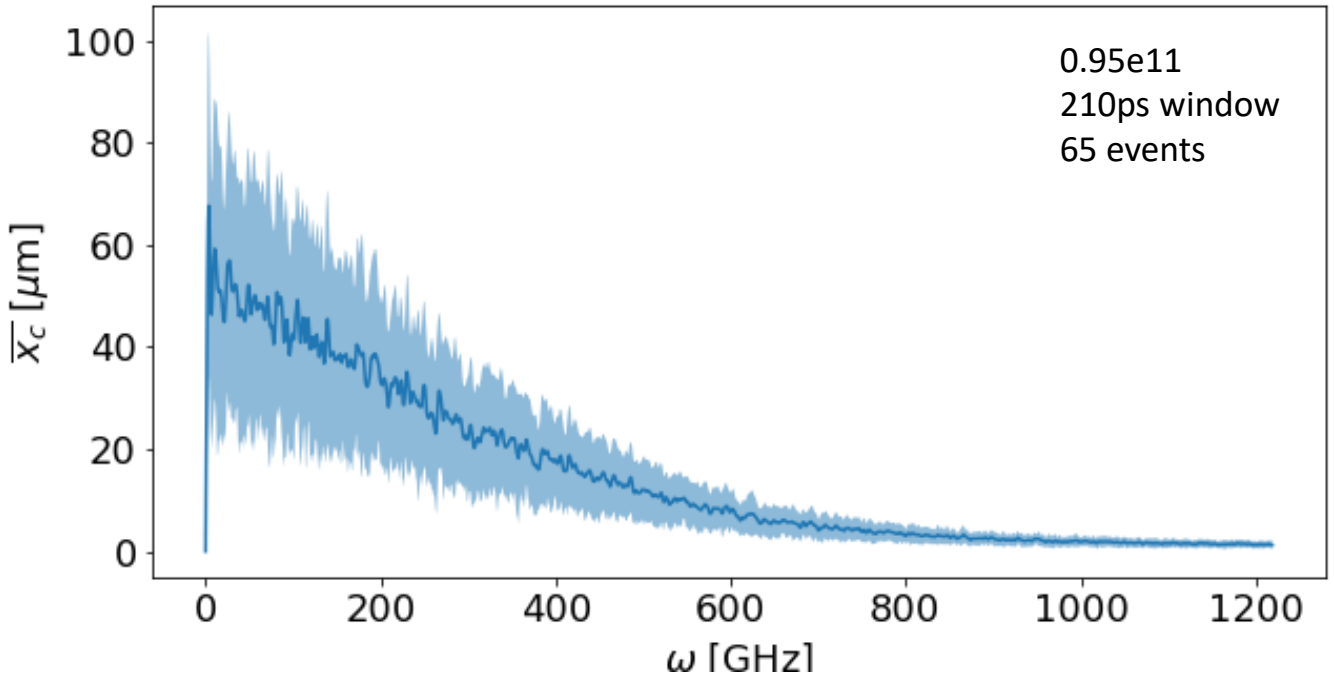

20
15
10
5
0
$\overline{r_c}$ [μm]
0
50
100
150
200
ω [GHz]
1.9e11
1ns window
20 events


20
15
10
5
0
$\overline{x_c}$ [μm]
0
50
100
150
200
ω [GHz]


20
15
10
5
0
$\overline{r_c}$ [μm]
0
50
100
150
200
ω [GHz]
2.7e11
1ns window
79 events

y-scale 5 times larger due to bigger bin size in x

Results



- Shorter time window of 210 ps
- Not transversely Gaussian → calculated mean position of the center
- Same trend as long timescale, no outstanding peeks

Results

- No observation of reoccuring frequency in the radial modulation of the bunch nor the centroid displacement
  - Be careful! This analysis could not determine the presence of sharp changes (as their spectrum is broad)

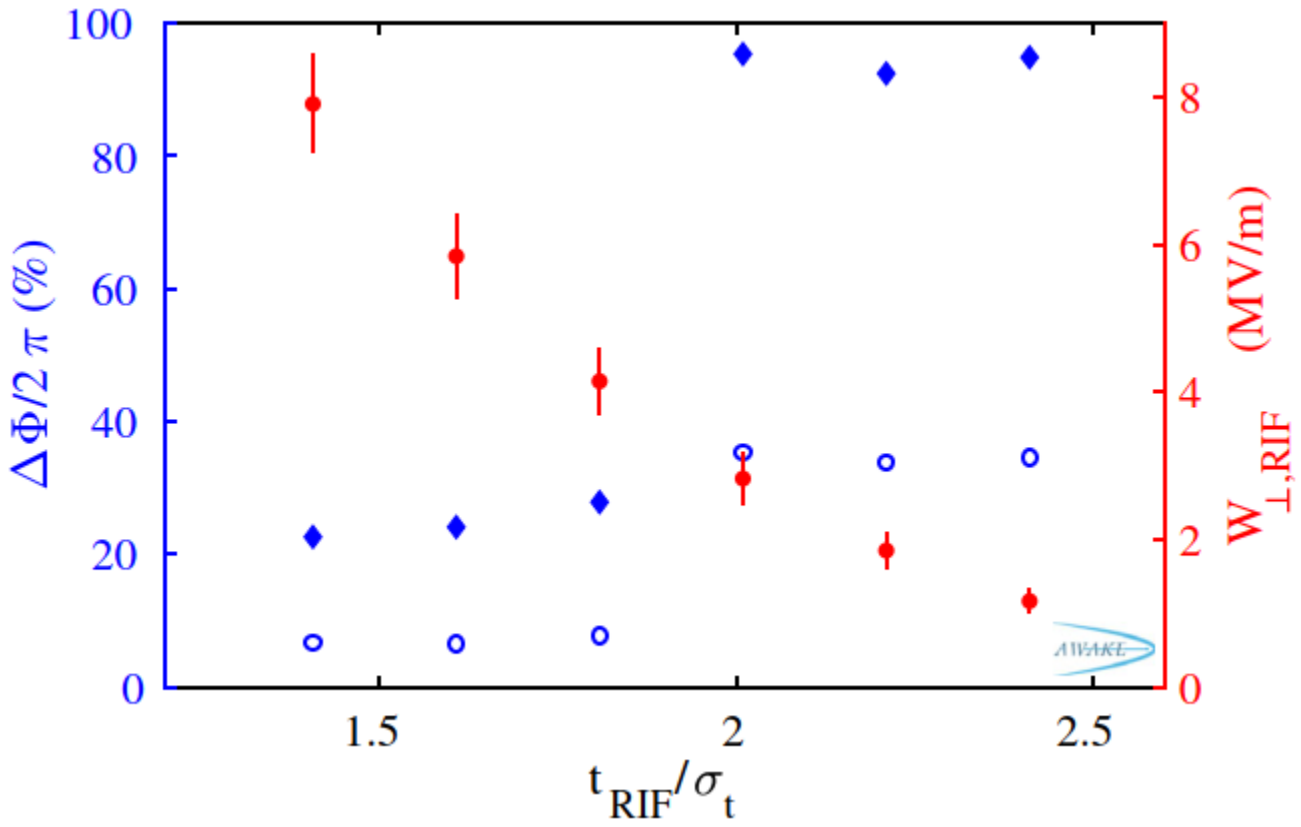
Seeding parameters

No need to introduce Fabian's work

How does the transition change for different bunch populations and profiles?

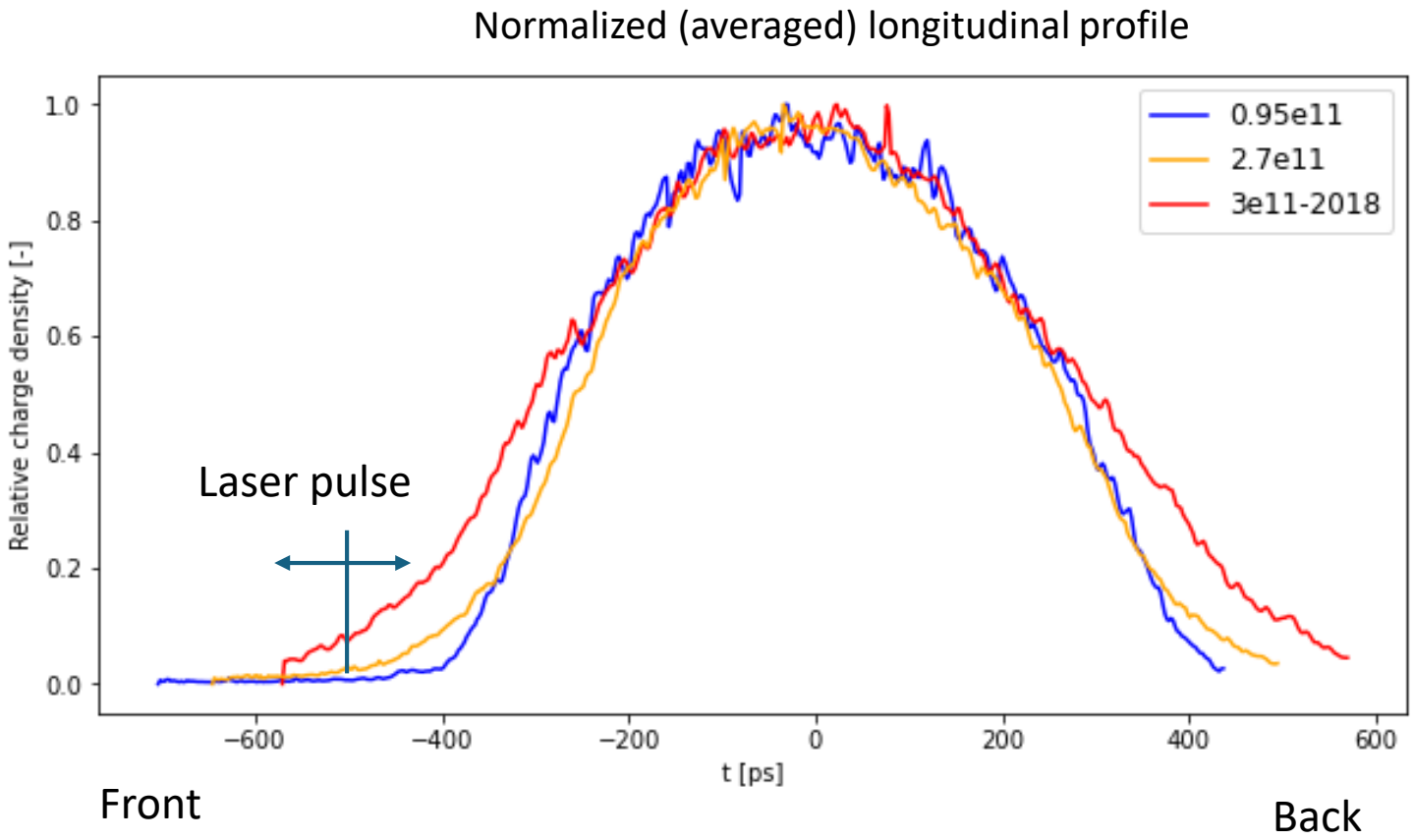
Hypothesis:

In case of "noise" scaling with the total charge the transition between SMI/SSM stays at the location where q/max(q) stays the same



Data from 2022

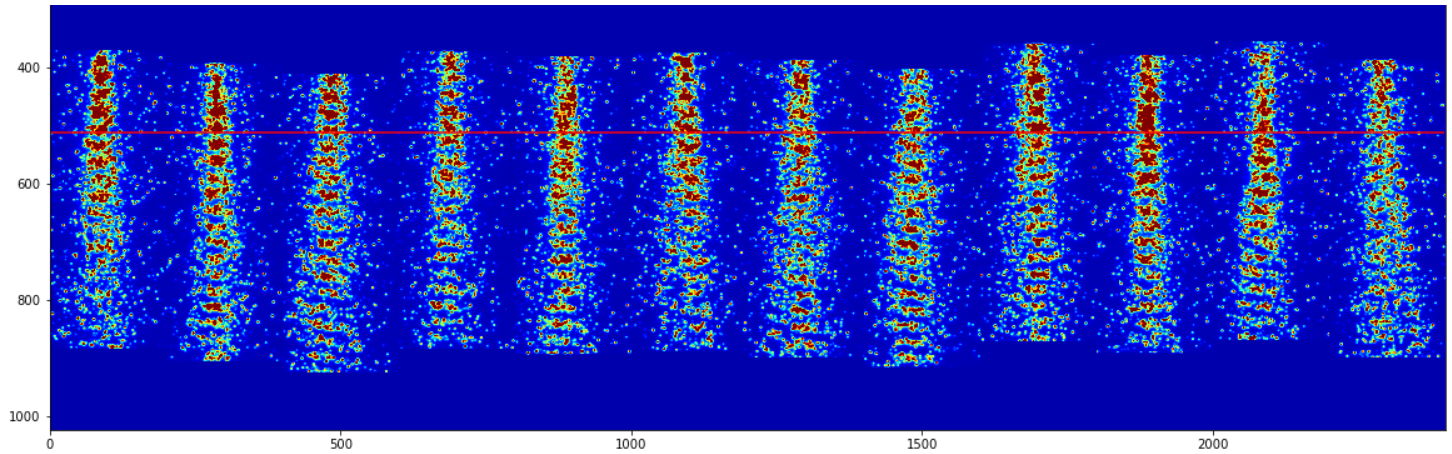
Measurement of seeding



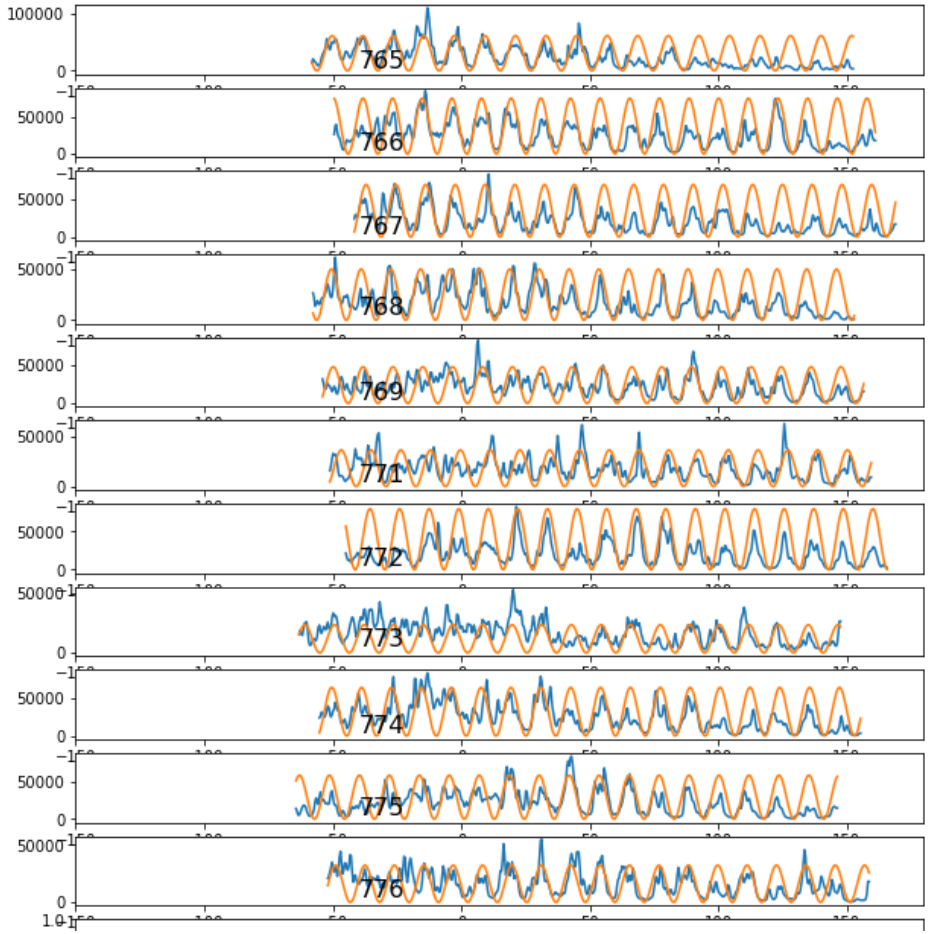
At least 4 timing settings (2 in SMI, 2 in SSM), at least 10 events per timing

Analysis

Waterfall plot of events:



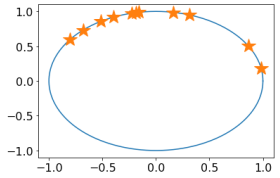
Lineout for DFT:



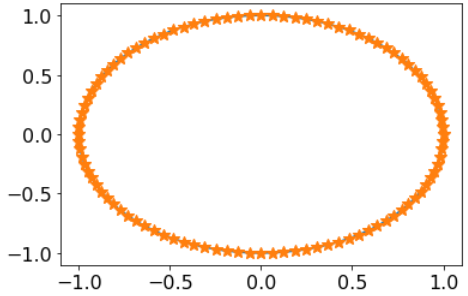
Array of phase:

[1.41, 1.98, 1.25, 2.32, 1.8, 0.18, 0.53, 1.76, 2.11, 2.5, 1.73]

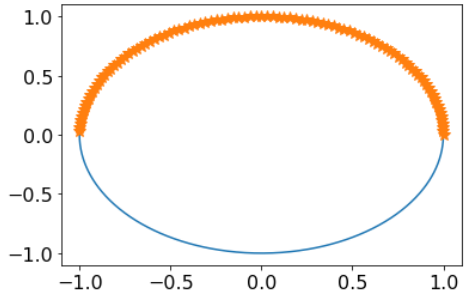
Circular variance = 0.21



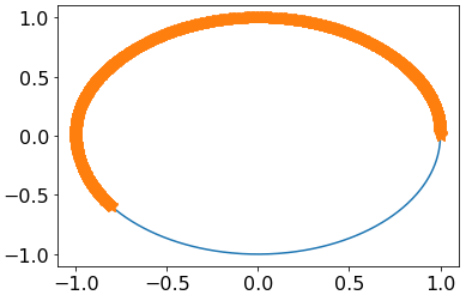
Circular variance (examples)



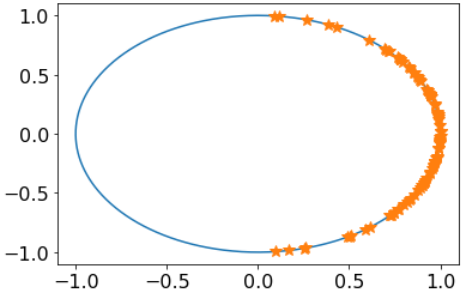
- Uniformly distributed population: cv = 1



- Uniformly distributed population in ½: cv = 0.36

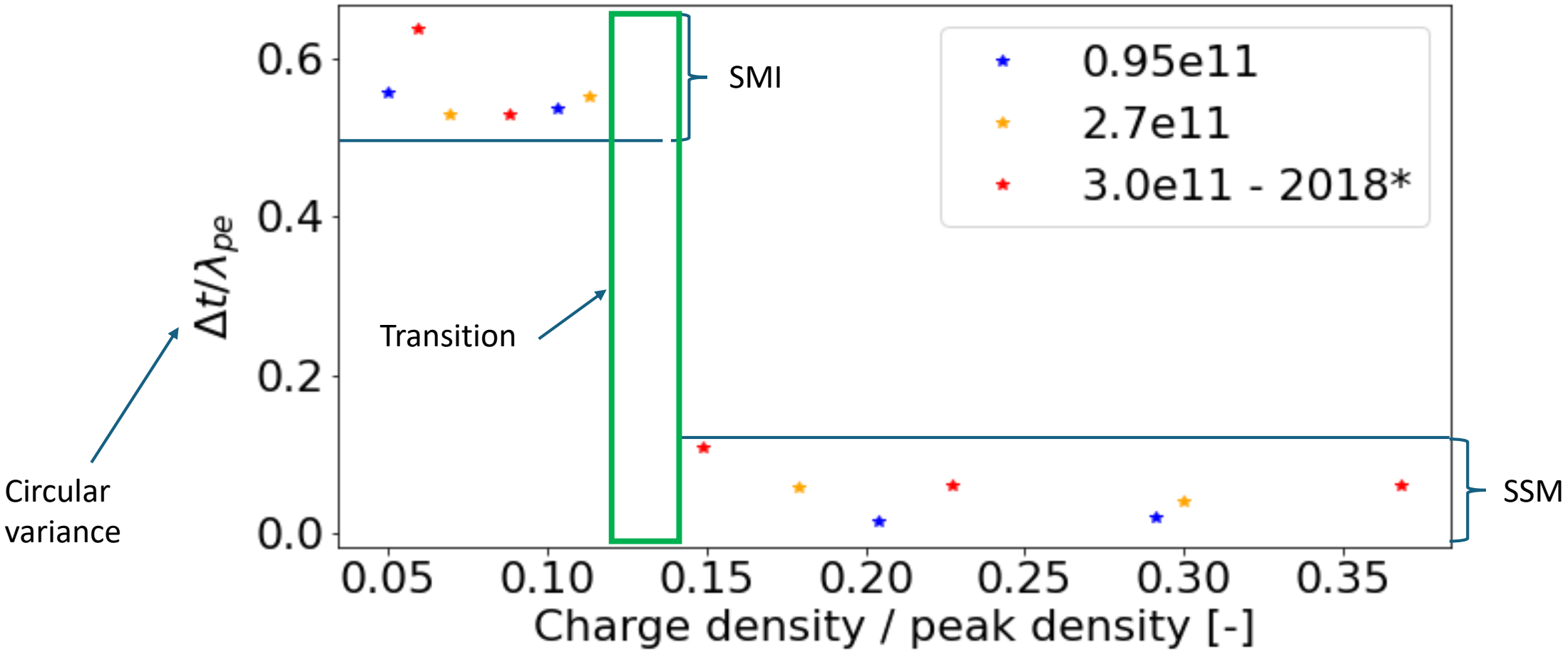


- Uniformly distrubuted population over 0.6: cv = 0.5



- Gaussian with σ = 0.57rad: cv = 0.15

Results



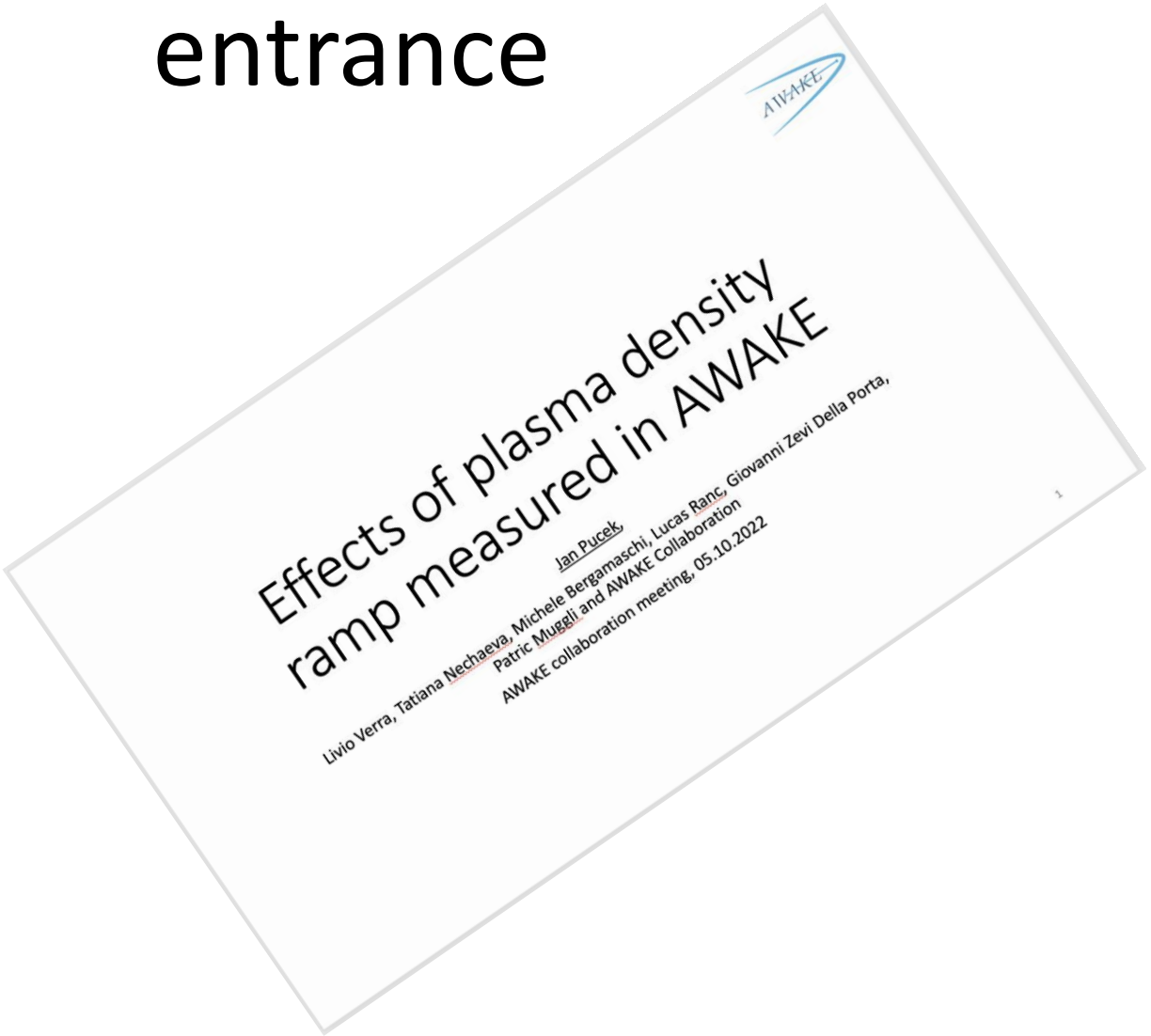
Transition between SMI and SSM happens between 12-15% of the charge density peak

Results

1. Validates the treshold being at the same relative charge density
2. If any structure present at the entrance, amplitude scales with total charge

Possible experiments in 2025 to complete the datasets

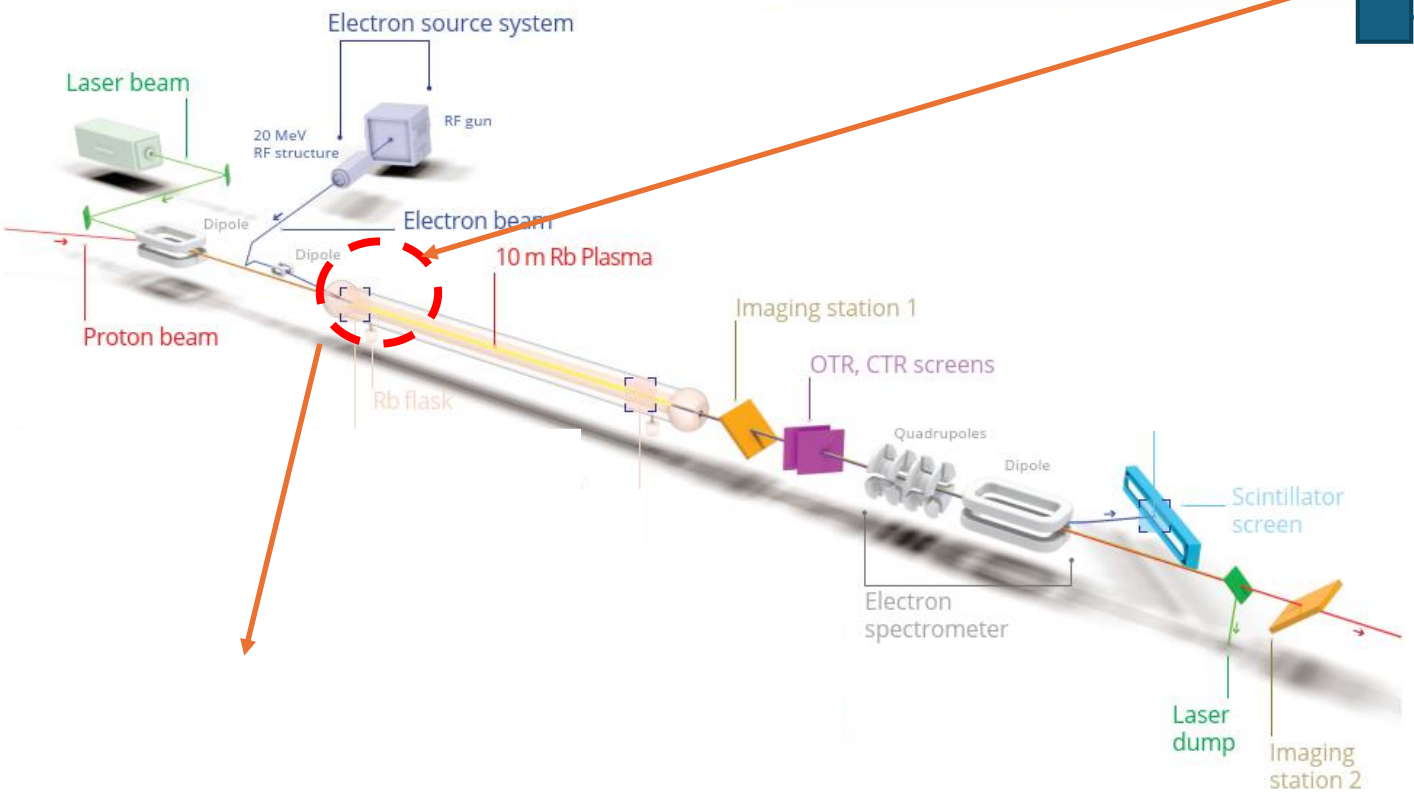
Study of the density ramp at the plasma entrance

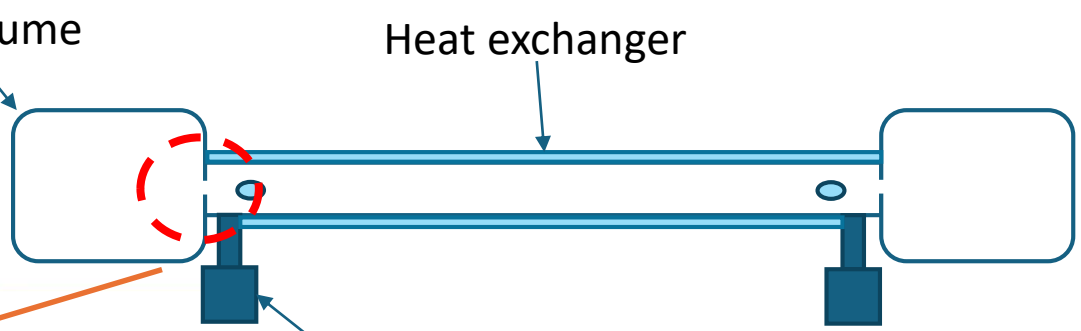


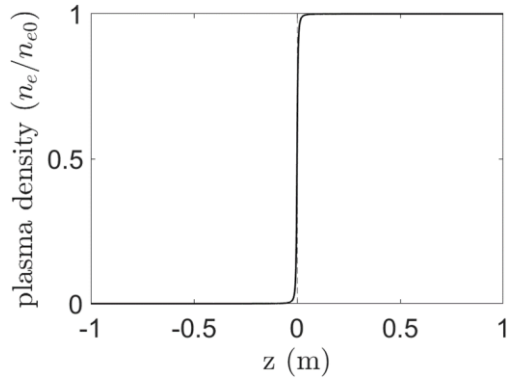
Last presentation 2 years ago…

Analysis using circ. var, done additional measurement

Introduction







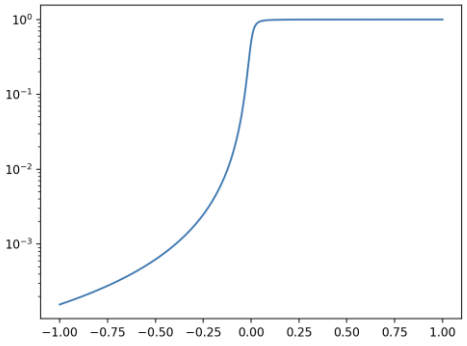
Courtesy of Pablo Morales Guzman*

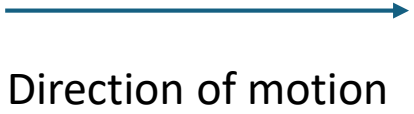
*G Plyushchev *et al* 2018 *J. Phys. D: Appl. Phys.* **51** 025203

*Danilatos G Proc. 22nd Int. Symp. Rarefied Gas Dynamics (2000)

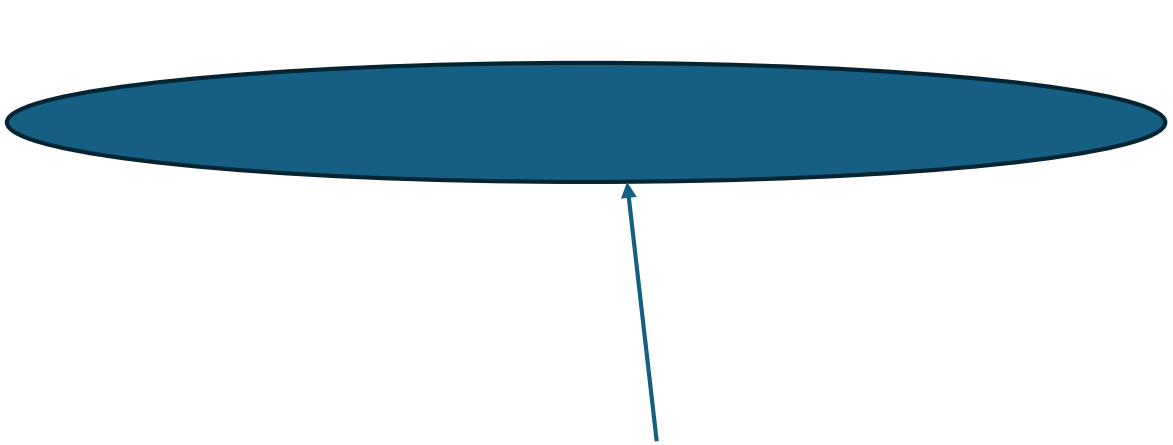
- $n_b >> n_e + p^+$ -> plasma e^- filament
- Defocusing of e^- bunch (seed, witness) when propagating within the p+ bunch

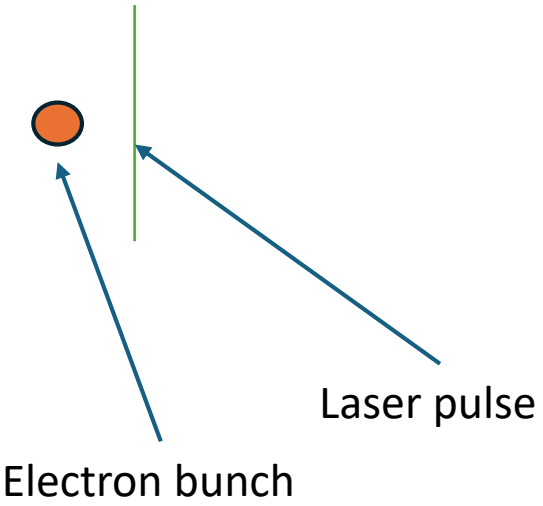
Plasma density in log scale





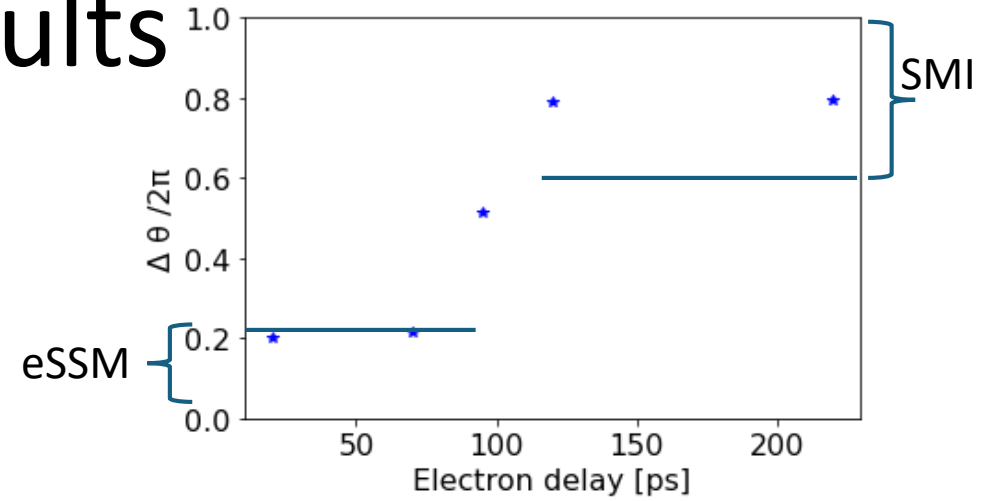
Measurement setup

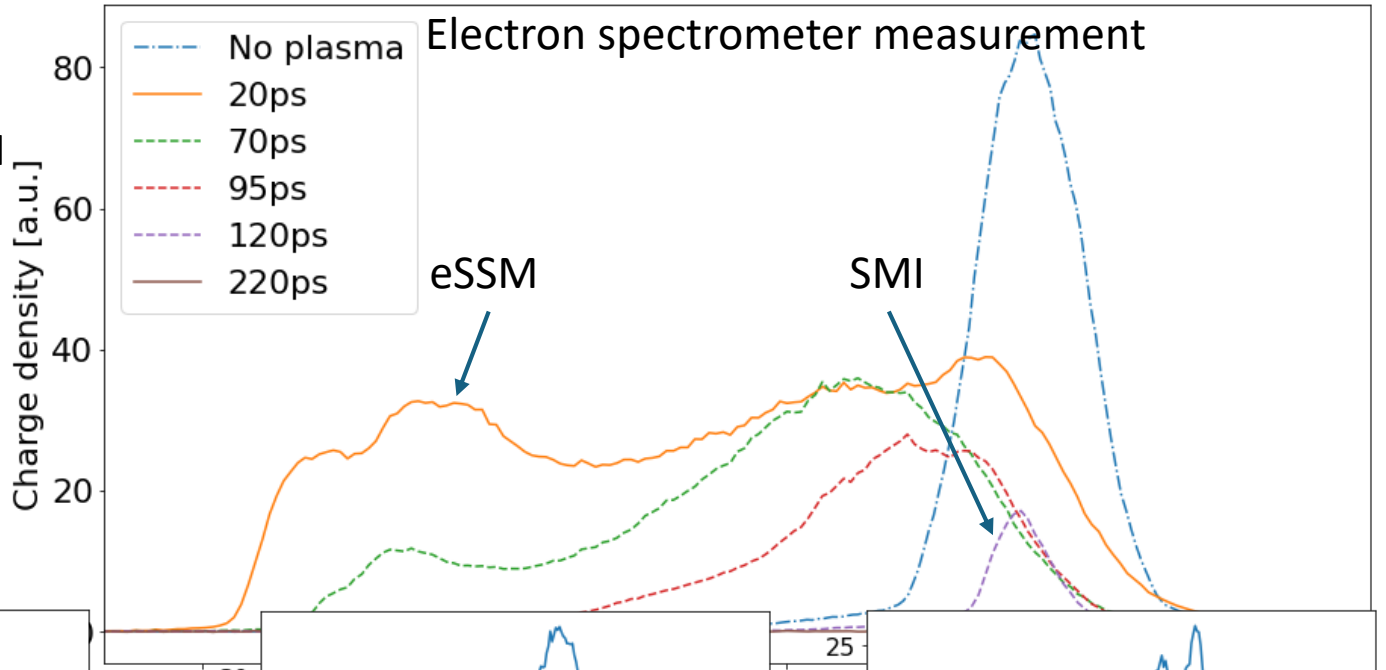


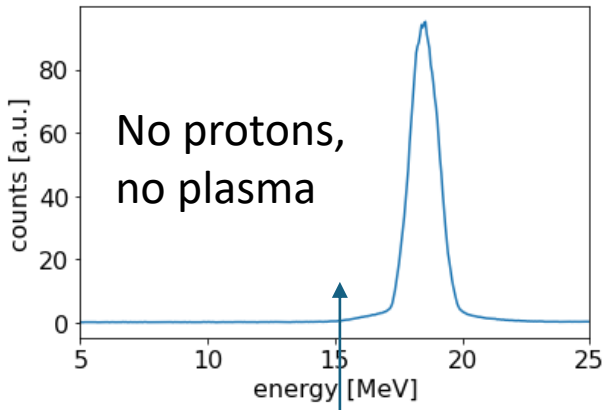


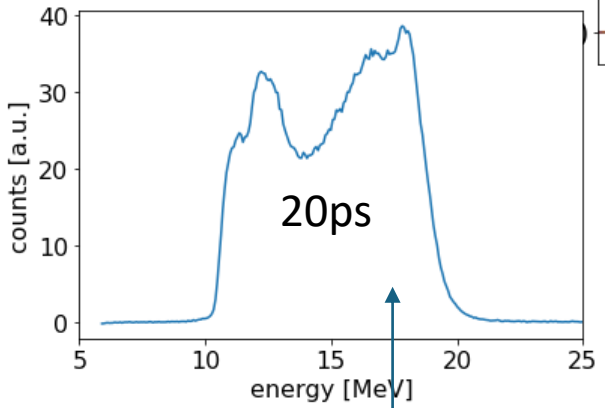
Multiple timing location of the e^- (the timing between p bunch and laser pulse constant)
Start at eSSM, measure the response of the p^+ and the propagated charge of the e^-

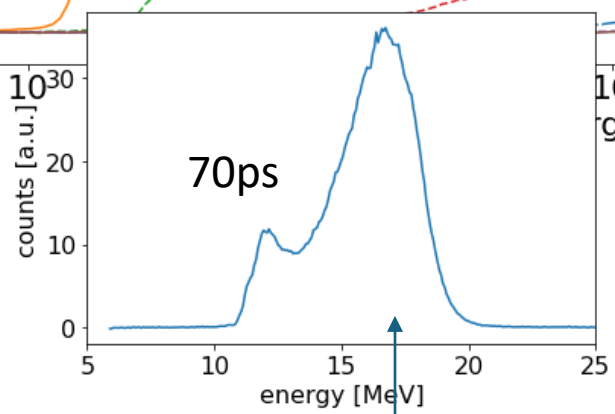
Results

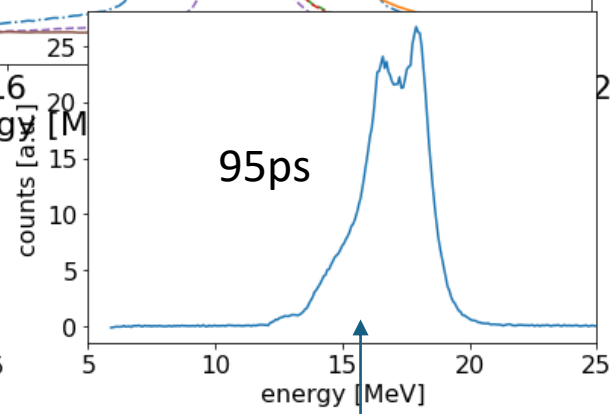

SMI
eSSM
Δ θ /2π
Electron delay [ps]

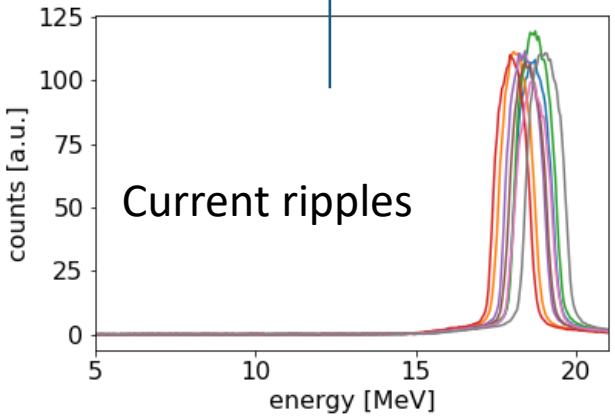

Electron spectrometer measurement
No plasma
20ps
70ps
95ps
120ps
220ps
eSSM
SMI
Charge density [a.u.]

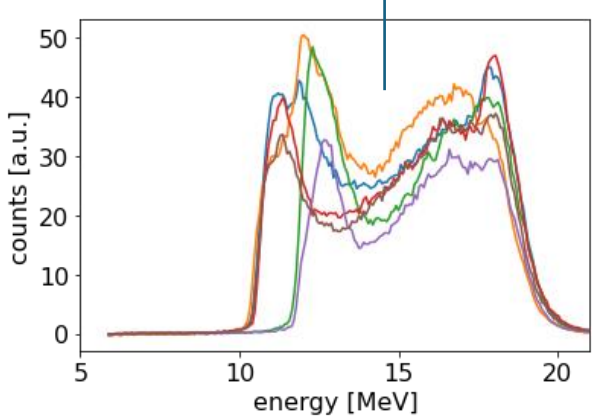

No protons,
no plasma
counts [a.u.]
energy [MeV]

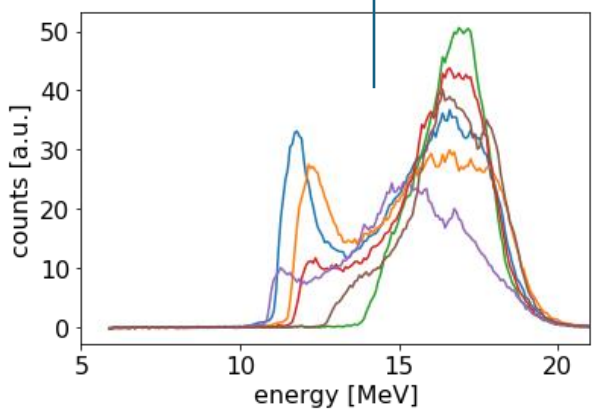

20ps
counts [a.u.]
energy [MeV]

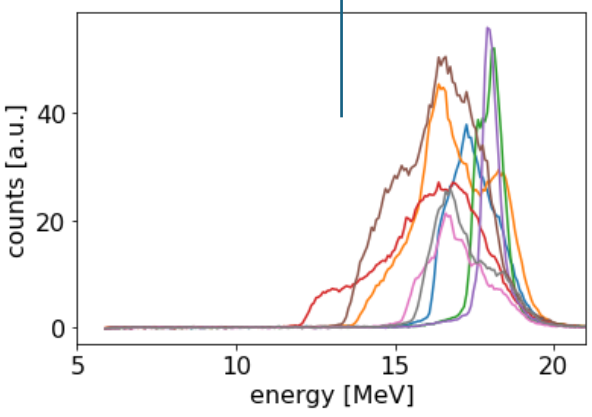

70ps
counts [a.u.]
energy [MeV]


95ps
counts [a.u.]
energy [MeV]


Current ripples
counts [a.u.]
energy [MeV]


counts [a.u.]
energy [MeV]


counts [a.u.]
energy [MeV]

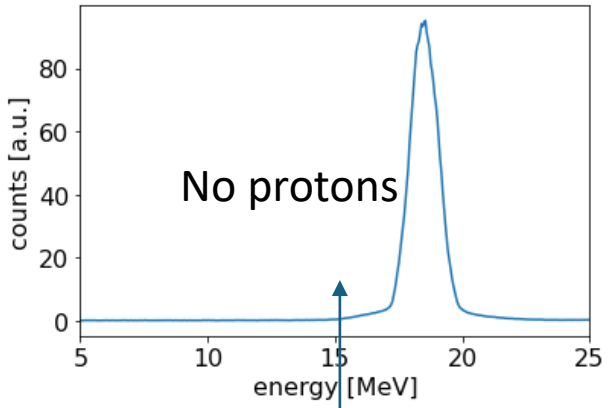

counts [a.u.]
energy [MeV]

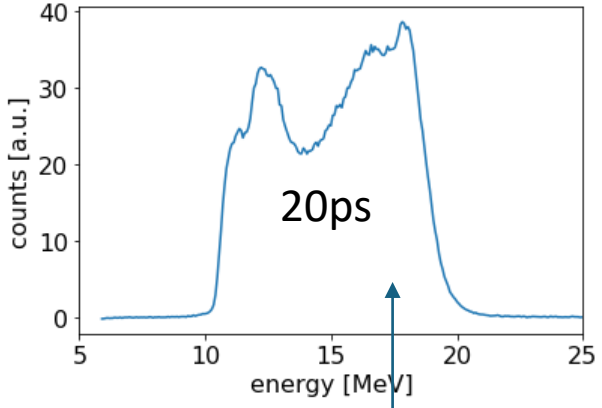
Conclusions

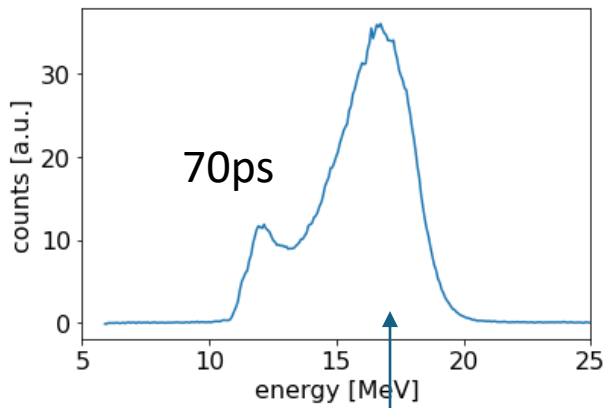
- The incoming proton bunch does not exhibit detectable periodic fluctuations that could seed hosing or self-modulation
- The transition between seeded self-modulation and the self-modulation instability occurs in the region of charge density equal to 12-15% of the charge density maximum
- Due to the plasma electron filament driven by the proton bunch in the ramp at the entrance of the VS, the electron witness bunch cannot be injected on axis within the proton bunch
  - (electron seeding possible)

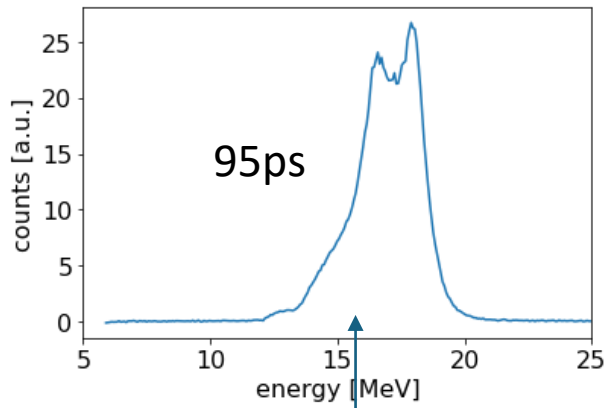
Thank you for your attention

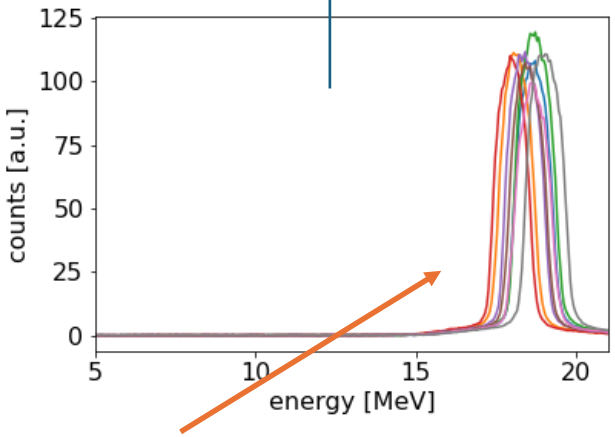
Backup

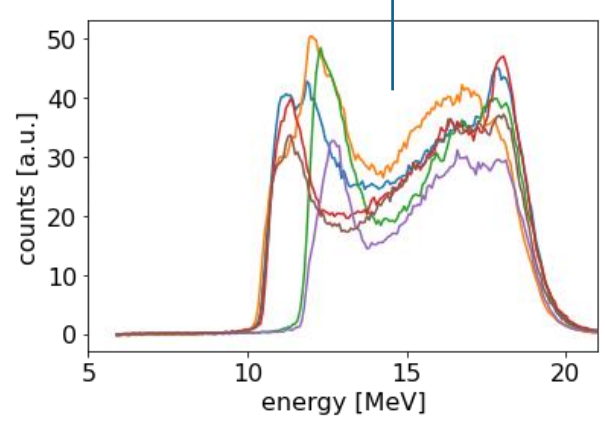


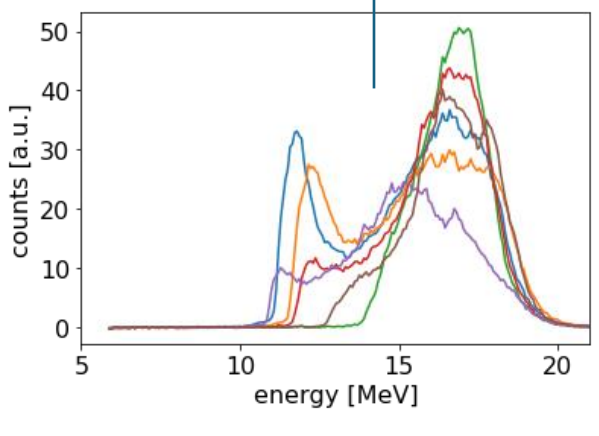


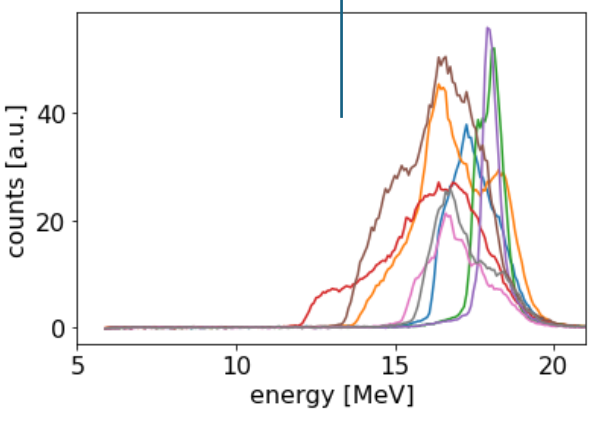












Low current in the spectrometer – visible ripples -> changed current for all others